

Binary Pulsars in Magnetic Field versus Spin Period Diagram

Y. Y. Pan^{1,2} • N. Wang¹ • C. M. Zhang²

Abstract We analyzed 186 binary pulsars (BPSRs) in the magnetic field versus spin period (B-P) diagram, where their relations to the millisecond pulsars (MSPs) can be clearly shown. Generally, both BPSRs and MSPs are believed to be recycled and spun-up in binary accreting phases, and evolved below the spin-up line setting by the Eddington accretion rate ($\dot{M} \simeq 10^{18} g/s$). It is noticed that most BPSRs are distributed around the spin-up line with mass accretion rate $\dot{M} = 10^{16} g/s$ and almost all MSP samples lie above the spin-up line with $\dot{M} \sim 10^{15} g/s$. Thus, we calculate that a minimum accretion rate ($\dot{M} \sim 10^{15} g/s$) is required for the MSP formation, and physical reasons for this are proposed. In the B-P diagram, the positions of BPSRs and their relations to the binary parameters, such as the companion mass, orbital period and eccentricity, are illustrated and discussed. In addition, for the seven BPSRs located above the limit spin-up line, possible causes are suggested.

Keywords pulsars: general; binaries: close; stars: neutron

1 Introduction

The pulsars (PSRs) in the binary systems are always convenient for us to determine their parameters such as the mass, origin and evolution. The majority of the binary pulsars (BPSRs) are millisecond pul-

sars (MSPs) with the spin period less than 20 milliseconds (Stairs 2004). Based on the data from the ATNF Pulsar Catalogue in November 2012, it has been found 2008 PSRs including 221 MSPs (136 binary PSRs versus 85 isolated ones). The companions of 186 binary PSRs are white dwarfs (170), neutron stars (9), main sequence stars (4) and planets (3), respectively. Much progress has been achieved in understanding the formation and evolution of the binary pulsars (BPSRs) (Bhattacharya et al. 1995; Stairs 2004; Manchester 2004; Lorimer & Duncan 2008; Tauris 2012; Tauris, Langer & Kramer 2012).

The distributions of the magnetic field (B) and spin period (P) are both almost bimodal with a dichotomy between the normal pulsars (PSRs) ($B \sim 10^{11-13} G$, $P \sim 0.1s - 10s$) formed directly by the supernova explosions and MSPs ($B \sim 10^{8-9} G$, $P \sim 1.4ms - 20ms$) that are recycled in the binary systems (Alpar et al. 1982; Radhakrishnan & Srinivasan 1982; Lorimer & Duncan 2008; Kaspi 2010; Wang et al. 2011). In the binary systems, with the accreting matter of $\sim 0.1 - 0.2 M_{\odot}$ from their companions, the neutron stars (NSs) can be spun-up to several milliseconds, while their magnetic fields decay to $\sim 10^{8-9} G$ (Bhattacharya & van den Heuvel 1991; Bhattacharya et al. 1995; van den Heuvel & Bitzaraki 1995; Melatos & Payne 2005; Zhang & Kojima 2006; Wang et al. 2011). With the 3D simulations of magnetohydrodynamics (MHD), the magnetic field affected by the accretion flow is depicted clearly (Kulkarni & Romanova 2008). When the accretion phase is finished, the radio emissions of the fast rotating NSs can be detected as MSPs (Alpar et al. 1982; Radhakrishnan & Srinivasan 1982; Tauris, Langer & Kramer 2012).

Evaporation of the companion star by the pulsar radiation explain explains why some MSPs are single (Kluźniak et al. 1988; Hessels 2008). This is more complicated in globular clusters: a companion can be dis-

Y. Y. Pan

N. Wang

Xinjiang Astronomical Observatories, Chinese Academy of Sciences, Xinjiang 830011, China. panyuanyue@xao.ac.cn

C. M. Zhang

National Astronomical Observatories, Chinese Academy of Sciences, Beijing, 100012, China. zhangcm@bao.ac.cn

rupted by encounter with another star. Direct evidence supporting the MSP spin-up model has been found, for instance, the accreting X-ray MSP SAX J1808.4-3658 ($B \sim 10^8 G$, $P = 2.49 ms$) discovered in the low mass X-ray binary system (Wijnands & van den Kils 1998), and the double pulsar PSR 0737-3039A/B (a MSP and a normal PSR in the binary system) (Burgay et al. 2003; van den Heuvel 2004; Lyne et al. 2004).

BPSRs are the most accurate clocks in the universe that can be exploited to form a MSP detect gravitational waves (Manchester 2004; Lorimer & Duncan 2008; Hobbs et al. 2010). BPSRs are the most accurate clocks in the universe. In addition, the BPSRs are significant systems for testing general relativity effects, e.g., the gravitational-radiation-induced orbit shrinking, gravitational red-shift and Shapiro delay (Kramer et al. 2006), based on which the NS mass can be measured in double neutron star systems using the periastron advance and with the high precision (Zhang et al. 2011).

This paper mainly focuses on the analysis of 186 BPSRs in the B-P diagram with the data from ATNF pulsar catalogue (Manchester et al. 2005). To understand the properties of these pulsars, we pay attention to their B-P positions relative to the spin-up lines, in relation to the companion mass, eccentricity and orbit period.

The structure of the paper is organized as follows: Sec.2 presents the detail study of the spin up lines under the different accretion rates. Here we also give the implications of the minimum accretion rate on the millisecond pulsar formation. In Sec.3, the distribution characteristics of BPSPs in the B-P diagram as a function of the binary parameters and the evolutionary scenario of binary pulsar are discussed. In Sec.4, we suggest the causes why seven BPSRs lie above the Eddington limited spin-up line. The discussions and conclusions are given in Sec.5.

2 Pulsars in B-P diagram and the evolutionary implications

2.1 The Spin-up line

If a NS, which has a symmetry axis of the magnetic field aligned with the rotation axis, spins up to the Kepler orbital period at the magnetosphere radius, a spin-up line will be obtained. It is also called the equilibrium spin period line expressed the relationship between the magnetic field and the spin period (Ghosh & Lamb 1977; Shapiro & Teukolsky 1983; Bhattacharya & van den Heuvel 1991; Ghosh & Lamb 1992; Burderi, D'Antona & Burgay 2002; Frank, King & Rame

2002; Camenzind M. 2007). However, the magnetosphere radius depends on many factors, such as the structure of the accretion disk and mass transfer form, etc (Tauris, Langer & Kramer 2011, 2012).

The equation of the spin-up line can be written as (Bhattacharya & van den Heuvel 1991):

$$P_{eq} = 2.4(ms) B_9^{\frac{6}{7}} \left(\frac{M}{M_\odot}\right)^{-\frac{5}{7}} \left(\frac{\dot{M}}{\dot{M}_{Edd}}\right)^{-\frac{3}{7}} R_6^{\frac{18}{7}}, \quad (1)$$

where P_{eq} is the "equilibrium" spin period, B_9 is the dipole magnetic field in units of $10^9 G$, \dot{M} is the accretion rate, \dot{M}_{Edd} is the "Eddington-limit" accretion rate ($10^{18} g/s$), R_6 is the stellar radius in units of $10^6 cm$ and M is the NS mass.

The spin period (P) and the spin-down rate (\dot{P}) of a PSR can be combined to yield an estimate of the strength of the dipole magnetic field (Manchester & Taylor 1977; Lyne & Smith 2006):

$$\begin{aligned} B &= \left(\frac{3c^3 I P \dot{P}}{8\pi^2 R^6}\right)^{\frac{1}{2}} \\ &= 3.2 \times 10^{19} \left(\frac{I}{10^{45} g cm^2}\right)^{\frac{1}{2}} R_6^{-3} (P \dot{P})^{\frac{1}{2}}, \end{aligned} \quad (2)$$

where I is the moment of inertia and R is the radius of the PSR. The moment of inertia is $I = (2/5)MR^2$. To evaluate the influence on the divided magnetic field by the choice of NS mass and radius, we rewrite Eq.(2) in terms of M and R :

$$B = 3.4 \times 10^{19} \left(\frac{M}{1.4M_\odot}\right)^{\frac{1}{2}} R_6^{-2} (P \dot{P})^{\frac{1}{2}}. \quad (3)$$

Eqs. (1-3) show us that the NS mass (M), radius (R) and accretion rate (\dot{M}) influence on the position of the spin-up line in the B-P diagram, and both NS masses and radius have influences on the derived strength of the dipole magnetic field. Mostly one takes a standard pulsar parameter ($M = 1.4M_\odot$, $R = 10^6 cm$) in the three equations. However, some measured NS masses are larger or smaller than $1.4M_\odot$. In binary systems, a mean value of $M = 1.46 \pm 0.30M_\odot$ has been derived for the 61 measured NS masses (Zhang et al. 2011). The NS radius has not yet been measured as accurate as its mass, and is usually estimated in the range $10 \sim 20 km$ by means of the models (Miller, Lamb & Psaltis 1998; Miller 2002; Larrimer & Prakash 2004; Hessels et al. 2006; Haensel, Potelin & Yakovlev 2007; Zhang et al. 2007).

The spin-up line equation Eq.(1) and magnetic field equation Eq.(3) show the relationships between the PSR magnetic field and NS radius as $B \propto R^{-3}$ and $B \propto R^{-2}$, respectively. If a NS radius changes from 10 km to 20 km, then the spin-up line will shift down by

$\text{Log}(8)=0.9$, whereas the PSR position will shift down by $\text{Log}(4)=0.6$, in $\text{Log}(B)$ axis of the B-P diagram. That is to say, the spin-up line will shift down ~ 0.3 relative to the PSR position in the $\text{Log}(B)$ axis of the B-P diagram.

Compared with the affection of the radius on the spin-up line and PSR position in B-P diagram, the variation of accretion rate will give much more influence on the spin-up line. From the observations, the accretion rates of the X-ray NSs span three orders of magnitudes, e.g., from $10^{15}g/s$ to $10^{18}g/s$ (Hasinger & van der Klis 1989; van der Klis 2000; Lamb & Yu 2004), and these variations will give rise to a considerably changes in the positions of the spin-up line in the B-P diagram, which are shown in Fig.1 for accretion rates: $10^{15}g/s$, $10^{16}g/s$, $10^{17}g/s$ and $10^{18}g/s$.

The distribution of the isolated and binary PSRs are also shown in Fig.1. The majority of the MSPs are distributed around the spin-up line with $\dot{M} = 10^{16}g/s$. It seems likely that most MSPs may be born at the positions near the spin-up line with $\dot{M} = 10^{17}g/s$, which is the generally observed accretion rate for the X-ray NSs in the Low-Mass X-ray Binaries (Bradt & McClintock 1983; Hasinger & van der Klis 1989; van der Klis 2000; Liu, van Paradijs & van den Heuvel 2007). This fact was also pointed out a decade ago by Lundgren et al. (1996) and Hansen and Phinney (1998).

2.2 Implications of the minimum accretion rate for MSP formation

It is noticed that only three MSPs, J0514-4002A, J1801-3210 and J1518+4904, lie below the spin-up line with $\dot{M} = 10^{15}g/s$. With the data from ATNF and Eq.(1), their positions correspond to the mean accretion rates $0.6 \times 10^{15}g/s$, $0.8 \times 10^{15}g/s$ and $0.9 \times 10^{15}g/s$, respectively. Possibly, their spin periods evolved to the present values due to the spin-down by of the electromagnetic emission. This suggest that there exists a critical minimum accretion rate $\dot{M} = 10^{15}g/s$ for a MSP formation, and the arguments for this view are described in the following.

At first, the real ages of MSPs have not yet been satisfactorily determined, although their characteristic ages can be a little longer than the Hubble age (Camilo, Thorsett & Kulkarni 1994). During the MSP spin-up evolution, the minimum amount of accreted mass required for a MSP to reach the spin period of several milliseconds is about $\Delta M_{cr} \sim 0.1 - 0.2M_{\odot}$ (Wang et al. 2011; Tauris, Langer & Kramer 2012), and the time of spin-up should be less than the Hubble time of about $t_H = 10^{10}\text{yrs}$ of a MSP. Thus, a critical

minimum mass accretion rate for the MSP formation can be estimated as:

$$\dot{M}_{cr} = \Delta M_{cr}/t_H \simeq 10^{15}g/s. \quad (4)$$

If the accretion rate is much lower than this critical value, the NS will have no chance to accrete sufficient mass to be spun-up to a period of a few milliseconds during the evolution. Based on the above argument, a critical minimum accretion rate $\sim 10^{15}g/s$ is suggested as a necessary condition for the MSP formation.

3 Binary Pulsars in the B-P Diagram

The evolution of the binary parameters of BPSRs, such as the companion mass, eccentricity and orbital period, are topics of interest. However, the BPSRs in GC can not help us to understand their properties very well (Hessels 2008; Tauris, Langer & Kramer 2012) since the stellar density of the cluster is much higher than that of the Galactic disk **which increase the collision** and capture of the stars. In this part, we ignore the 75 BPSRs in the GC, and study the distribution of 103 BPSRs in the Galaxy disk (GD) that have spin period P and magnetic field B in the B-P diagram.

3.1 BPSRs with the Different Parameter Conditions

In Fig. 2a, we notice that the BPSRs with the small and inter-mediate companion mass, $M_c < 0.1M_{\odot}$ and $0.1M_{\odot} < M_c < 0.45M_{\odot}$ as defined by Stairs (2004) occupy about 12.6% and 61.2% in the total BPSRs, respectively. In Fig.2b, the percentages of the BPSRs with the low eccentricity ($e < 0.1$), mediate eccentricity ($0.1 < e < 0.5$) and high eccentricity ($e > 0.5$) occupy 85.1%, 6.9% and 8.0% of the total, respectively, which indicates that the eccentricity of BPSR has deceased in the evolution process. In Fig.2c, most of the BPSRs with the orbital period $P_{orb} < 100d$ share the spin period less than $\sim 100ms$. Then those with long orbital period $P_{orb} > 100d$ are distributed from $\sim 30ms$ to $\sim 1s$.

3.2 Evolution Scenario of Pulsar in Binary System

There are many cases for the evolutions of binary systems (Lipunov & Postnov 1984; Tauris, Langer & Kramer 2011, 2012). The companion mass plays an important role in the evolution of binary system (Taam & van den Heuvel 1986; Shibazaki et al. 1989). The star with a mass over about 8 solar masses experiences a supernova explosion firstly, leaving a NS with a high magnetic field of

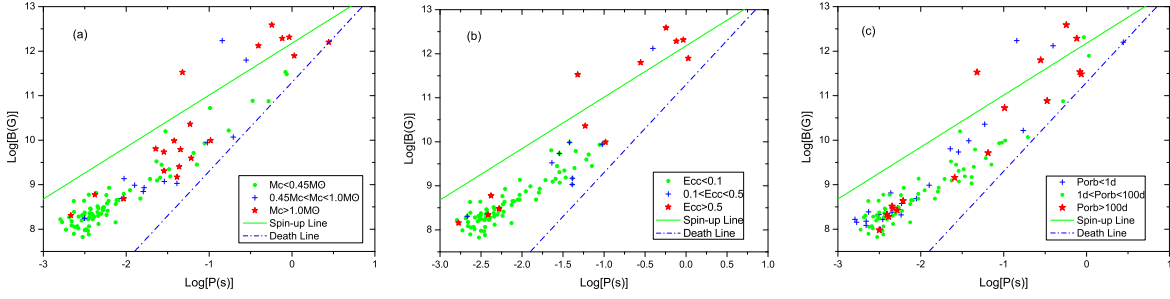


Fig. 2 B-P diagrams plotted with various parameter conditions of 103 BPSRs, as shown in the figures, e.g. companion mass (a), eccentricity (b) and orbital period (c). About 86.4% of the BPSRs **have low** magnetic fields $B < 10^{10.5}G$, which is considered as the threshold for the normal PSRs (Hartman, Portegies & Verbunt 1997).

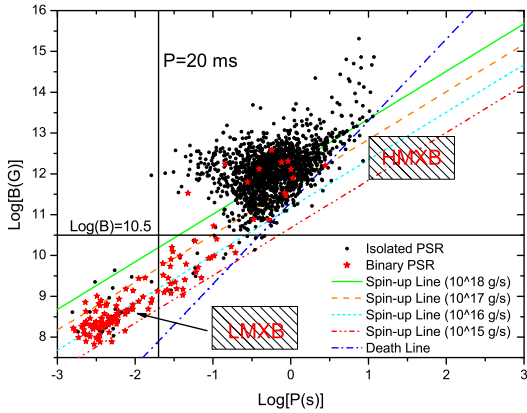


Fig. 1 The magnetic-field versus spin-period diagram for 2008 PSRs (data from ATNF pulsar catalogue as at November 2012). 221 MSPs ($P < 20ms$) are shown, including the isolated ones (85) and those in the binary systems (136). The solid, dash, short dash and dash dot-dot lines stand for the spin-up lines with the different accretion rates $10^{18}g/s$, $10^{17}g/s$, $10^{16}g/s$ and $10^{15}g/s$, respectively, as shown in Eq. (1). The dash dot line is the death line by the theoretical model of decreasing the radio emission of pulsar (Bhattacharya & van den Heuvel 1991; Ruderman & Sutherland 1975). The isolated and BPSRs are labeled by dots and stars, respectively.

$\sim 10^{12-13}G$ and spin period of > 10 milliseconds, like the Crab pulsar ($B \sim 10^{12}G$, $P \sim 30ms$). Such a new born pulsar in the B-P diagram lies in the region A0 in Fig.3, from where the pulsar starts to evolve to A1 on account of the electromagnetic emission with a more or less constant magnetic field within the time about $\sim 10^7yr$.

The life time of NS spin-up will be inversely related to the mass of its companion, since heavier stars have shorter life spans, which can be approximated by the formula of the main sequence age $T \sim 10^{10}(yr)(M/M_{\odot})^{-2.5}$. With the accretion mass provided by the companion, the NS will be spun up. The evolution can be classified in the following three types (Shibazaki et al. 1989; Taam & van den Heuvel 1986).

(1) High Mass X-ray Binary (HMXB) case: the companion mass is about $10-25M_{\odot}$. The binary system will be the PSR+massive (PSR+NS) star if the system gets the accretion mass $\sim 0.0001M_{\odot} - 0.001M_{\odot}$ ($\sim 0.01M_{\odot}$), while the evolution path might be A1-A2 (A1-A2-A3). The accretion evolution will stop at the spin-up line, where the stellar spin frequency equals the orbital Keplerian frequency at the edge of the magnetosphere.

(2) Intermediate Mass X-ray Binary (IMXB) case: if the companion mass is in the range of $3-10M_{\odot}$, the NS spin-up evolution will continue the procedure of HMXB case following up the route A1-A2-A3 or even to position A4 along the spin-up line. The NS will accrete about $\sim 0.001M_{\odot} - 0.1M_{\odot}$ to form a NS+WD(heavier) systems, with the magnetic field $B \sim 10^9-10^{10}G$ and the spin period $P \sim 20 - 100ms$.

(3) Low Mass X-ray Binary (LMXB) case: if the companion mass ranges at $\sim 0.8 - 3M_{\odot}$, the NS will evolve to the position A4 with the magnetic field $B \sim 10^8-10^9G$ and the spin period $P < 20ms$, while the NS accretes $> \sim 0.1 - 0.2M_{\odot}$ to form a MSP+WD(lighter) binary system (Zhang et al. 2011).

From the above mentioned scenarios of BPSR evolutions, the companion mass and accretion rate might play important roles in the evolution of binary system (Wijers 1997; Shibazaki et al. 1989; Taam & van den Heuvel 1986).

4 Binary pulsars above the spin-up line

In the binary systems, generally, the PSRs will evolve below the spin-up line after accreting a sufficient amount of mass from their companions. However, seven BPSRs lie above the Eddington spin-up line ($\dot{M} = 10^{18} g/s$) with the magnetic fields $> 10^{11.5} G$, as shown in Fig.4. Their parameters are listed in Tab. 1. According to their companion masses, these seven BPSRs are divided them into two types: the ones with the massive stars ($M > 4.0 M_{\odot}$) and the others with the degenerate stars (NS or WD).

4.1 Type-I: BPSRs with Massive Companions

Type-I includes four binary pulsars. Three of them (No.1,3 and 4 in Fig.4) are with B or Be star companions (Kaspi et al. 1994; Manchester et al. 2001; Stairs, Manchester & Lyne 2001; Stairs et al. 2003; Wang et al. 2004). PSR J1638-4725 (No.2 in Fig.4) has a massive star as its companion ($M_c > 8.08 M_{\odot}$) which is in the main sequence stage. Its radio emission disappears near the periastron because of the absorption and scattering by the dense stellar environment. During the radio-quiet phase, X-rays that are produced by the accretion matter onto the NS magnetosphere are likely to be detectable (McLaughlin 2004). By considering the parameters of this pulsar, such as the strong magnetic field ($B \sim 1.93 \times 10^{12} G$), not long characteristic age ($\tau = 2.53 Myr$), very long orbital period ($P_{orb} = 1940.9d$) and very high eccentricity ($e = 0.955$),

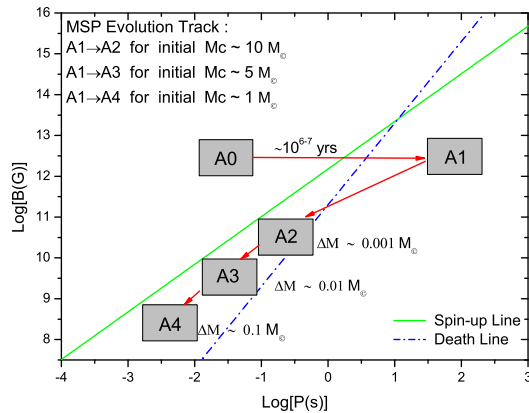


Fig. 3 Evolution tracks of binary pulsars in B-P diagram.

we think that it has little possibility to accrete the matter from its companion star, therefore it is inferred that this pulsar is a non-recycled BPSR, born at the position A0.

The common characteristics of these four BPSRs are: they all have high eccentricities, long orbital periods, massive companions in the main sequence stage. In all cases the pulsars are new born ones with spin-down ones of less than a million years; they are not (yet) accreting, and are in the "non-recycled" phase. These four BPSRs are on the way of evolution from A0 to A1 as shown in Fig.3, where the first born PSRs are experiencing the spin-down with little accretion mass.

4.2 Type-II: BPSRs with Degenerate Star Companions

J1906+0746 (No.5 in Fig.4) is a non-recycled PSR ($1.25 M_{\odot}$) in a double neutron star system. Its companion is a recycled PSR with the mass of $1.37 M_{\odot}$ (Lorimer & Duncan 2008). The short characteristic age of J1906+0746 ($\tau = 113000 yr$) indicates that it is a recently formed young PSR after the core collapse, which should be the reason why its B-P position lies above the spin-up line ($10^{18} g/s$).

B1820-11 (No.6 in Fig.4) possesses a slightly massive WD ($M_c = 0.78 M_{\odot}$) (Portegies, Simon & Yungelson 1999; Stairs 2004) as its companion. From its parameters ($\tau = 3.22 Myr$, $B = 6.29 \times 10^{11} G$ and $P = 279.829 ms$), we suggest that it is a young recycled PSR. The evolution history of this PSR can be understood in this way: the initial magnetic field of NS can be as high as $B \sim 10^{13} G$, and it evolves from the position A1 to A2 after accreting the companion mass about $\sim 0.001 M_{\odot}$, while one to two magnitude orders of magnetic field has been deducted. Due to its high eccentricity and

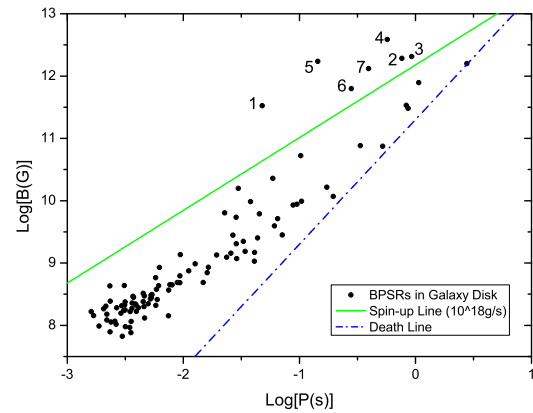


Fig. 4 B-P diagram for 103 BPSRs with the spin period and magnetic field in GD. The plots share the similar meanings to those of Fig.1.

large orbital period, B1820-11 might not get enough accreting mass from its companion. In Eq.(1) it is assumed that the spinning axis is parallel to the magnetic axis, whereas in Eq.(3) the perpendicular condition is assumed. Therefore the position of the spin-up line will be fuzzy because the angle of the spinning axis to the magnetic axis is unknown. The position of PSR B1820-11 might be below the spin-up line.

J1141-6545 (No.7 in Fig.4) is a PSR of mass $1.3 M_{\odot}$ with an optical WD ($1.02 M_{\odot}$) as its companion in the binary system (Antoniadis et al. 2011). With the short orbital period ($P_{orbit} = 0.1977d$) and slightly low eccentricity ($e = 0.1719$), it can be derived that this PSR acquired the accretion mass easily and followed up the recycled process. Its position upon the spin-up line can be explained by two possible reasons: the first one is the same reason as for B1820-11, and the second one is that the PSR may have experienced the accreting induced collapse (AIC) of a white dwarf (WD) (van den Heuvel & Bitzaraki 1995; van den Heuvel 2009).

It is noted that the spin-up line with Eddington rate in B-P diagram is also influenced by the spin-up torque and radiation pressure in disk, which has been studied by some researchers (Kulkarni & Romanova 2008; Ghosh & Lamb 1992; Lamb & Yu 2004).

5 Discussions and Conclusions

In this paper, we investigate the 186 BPSRs (136 MSPs) in the B-P diagram. The origin and evolution information of their progenitors can be inferred by analyzing their positions relative to the spin-up lines in the B-P diagram. The following results have been obtained:

(1) The observations of X-ray NSs in binary systems show that $\dot{M} = 10^{17} g/s$ is a conventionally detected mass accretion rate (van der Klis 2000; Liu, van Paradijs & van den Heuvel 2007). In the B-P diagram, most BPSRs are distributed around the spin-up line for $\dot{M} = 10^{16} g/s$, which means that most BPSRs should be born at the positions near the spin-up line ($\dot{M} = 10^{17} g/s$), from where the PSRs experience the spin-down time of $\sim 10^{8-9} yr$ after the onset of the radio PSR emissions.

(2) To form a MSP, the mass of about at least $\sim 0.1-0.2 M_{\odot}$ should be accreted from the companion (Wang et al. 2011; Zhang et al. 2011). Thus, within a Hubble time, the required minimum accretion rate is $\dot{M} = 10^{15} g/s$. In other words, if the accretion rate is less than this critical value, a NS will accrete the mass less than $0.1 M_{\odot}$ and may evolve to a recycled PSR with a slightly longer spin period than 20 ms. Furthermore, we stress that this critical minimum accretion rate is an averaged value in the whole binary accretion history.

(3) It is noticed that the position of a pulsar and its spin-up line in the B-P diagram are slightly affected by the choices of the NS mass and radius, and the radius has more influence than the mass. However, unlike the measurements of the NS masses, the NS radius has not yet been satisfactorily determined from observations (Zhang et al. 2007, 2011). It is usually estimated to be in the range of 10-20 km, thus we cannot sure if the standard value of $R = 10 km$ introduces a big error in defining the PSR position in the B-P diagram.

(4) The classification of the BPSRs by the conditions of the companion mass, eccentricity and orbit period have given us a clear illustrations of their properties in B-P diagram. Most millisecond BPSRs with small companion masses ($< 0.45 M_{\odot}$) should be long lived, such as $10^{8-9} yr$, while $\sim 0.1 - 0.2 M_{\odot}$ is accreted during the accretion phase. In addition, the majority millisecond BPSRs share the small eccentricities $e < 0.01$, which implies that their orbits were circularized during the recycle process. In fact, there have already been many researches on this, e.g. by Tauris & Sacinije (1999), Tauris, van den Heuvel & Savonije (2000), and Tauris, Langer & Kromer (2012). However, there is no clear and simple relation between the orbital period and BPSR evolution, which hints that the evolution of the orbital period may be complicated in the recycle process.

(5) To interpret why the seven BPSRs lie above the limit spin-up line, we start with the binary histories of these sources. The first four BPSRs have the heavy star companions ($M_c > 4 M_{\odot}$) staying at the main sequence phases, and they are still spinning down via magnetic dipole radiation. The recycle processes of these systems have not yet started, so they still go on the evolutionary tracks of the first pulsar spin-down. The fifth BPSR lies in a double NS system (NS+NS). However, unlike the system PSR 1913+16 in which the recycled pulsar has been observed, the observed pulsar J1906+0746 should be the normal and the secondly formed pulsar. Namely, its companion should be a recycled NS that has not yet been observed as a pulsar. Thus this PSR is experiencing the spin-down by the electromagnetic radiation towards the death line. Both the sixth and seventh pulsars are similar, which have the degenerate white dwarfs (NS+WD) as companions. They might be the newly formed recycled pulsars with the Eddington rate, while either the particular accretion torque and disk structure or large NS radii may be responsible for their slightly passing through the spin-up line.

In summary, the study of BPSRs in B-P diagram has provided us the clues on their accreting evolution histories, which is a helpful tool in constructing a link between the radio MSPs and their progenitors, where the

Table 1 Parameters of Seven Binary Pulsars above the Spin-up Line

No.	Name	P/ms	P_{orb}/d	e	M_C/M_\odot	τ/yr	B/G	type
1	B1259-63	47.763	1236.724	0.8699	4.14	332000	3.34E11	NSMS
2	J1638-4725	763.933	1940.9	0.955	8.08	2.53E6	1.93E12	NSMS
3	J0045-7319	926.276	51.1695	0.8079	5.27	3.29E6	2.06E12	NSMS
4	J1740-3052	570.31	231.0297	0.5789	15.82	354000	3.86E12	NSMS
5	J1906+0746	144.072	0.166	0.0853	1.37	113000	1.73E12	DNS
6	B1820-11	279.829	357.762	0.7946	0.78	3.22E6	6.29E11	NSWD
7	J1141-6545	393.899	0.1977	0.1719	1.02	1.45E6	1.32E12	NSWD

influences by their binary parameters can be properly investigated. The 186 binary pulsars from the 2008 pulsar sample have been analyzed, and more samples are required to present robust conclusions on the evolutions of binary pulsars. With the recent construction of the powerful radio telescope, five hundred meter aperture spherical telescope (FAST), more than 4,000 new pulsars are expected to be observed in this decade (Nan 2006; Smits et al. 2009; Nan et al. 2011), while there will be a big sample set of binary pulsars, e.g. about 500 ones, to show a clear trend of MSP evolution.

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